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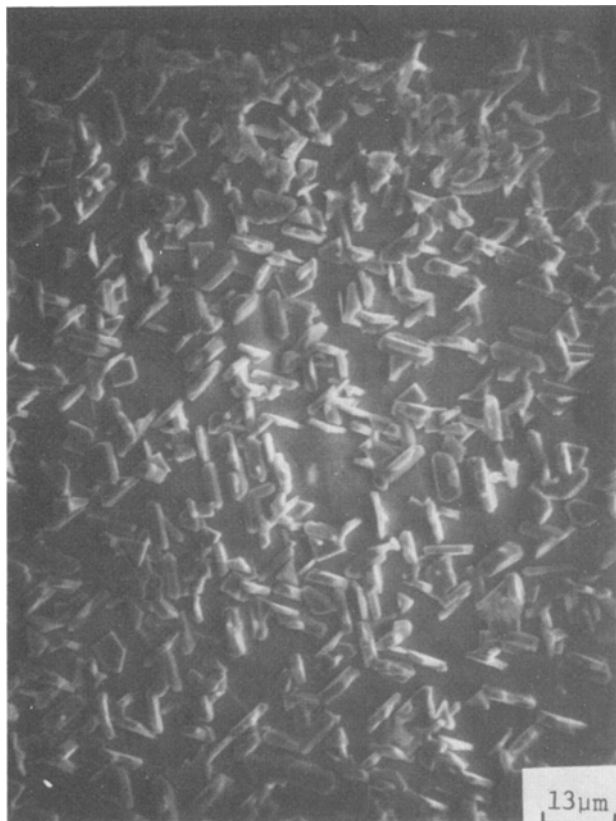


Fig. 9. Tin selenide growth on cleaved (111)BaF₂ (SEM photograph).

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Brief Communications



Ohmic Contacts to Al-Implanted ZnSe

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The production and characterization of ohmic contacts is an important part of semiconductor technology. In this paper we report the formation of ohmic contacts on ZnSe, by evaporating or sputtering Au or Pt onto the Al-implanted, n-type substrate. Although these metals normally form rectifying Schottky barriers on n-type ZnSe, such barriers are precluded if the implanted layer is degenerate. An advantage of Au or Pt contacts is that much higher operating temperatures are possible than with the commonly used In or Ga.

The Al implantation was carried out at 90 keV to a dose of 10^{15} ions/cm² at room temperature.³ The substrate was a high-resistivity ($\sim 10^9$ ohm-cm) crystal cut to expose the (110) face. Before implantation, the surface was mechanically polished and chemically

etched at 90°C for 1 min in a mixture of 2 parts H₂SO₄ and 3 parts saturated aqueous solution of K₂Cr₂O₇, followed by a 20 sec rinse in a boiling 25% solution of NaOH. In a previous paper (1) it was reported that crystals implanted in such a manner and annealed in evacuated fused-silica ampuls for 4 hr at 900°C showed nearly degenerate electrical characteristics, with an effective electron mobility of about 4 cm²/V-sec and an effective sheet carrier concentration of about 10^{15} cm⁻². When unimplanted samples and samples implanted with Ar ions were annealed under the same conditions, they remained highly resistive. This showed that the Al implantation was essential for the production of the conductive layer, i.e., neither the annealing alone nor the radiation damage produced by Ar ions were sufficient to appreciably change the conductivity of the original substrate. The thickness of the implanted and annealed conductive layer was roughly checked by the use of the etch described above. This etch removes about 50 Å/sec from unimplanted ZnSe at room temperature and the rate for implanted ZnSe

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³The ion implantation was done at NASA Langley Research Center.

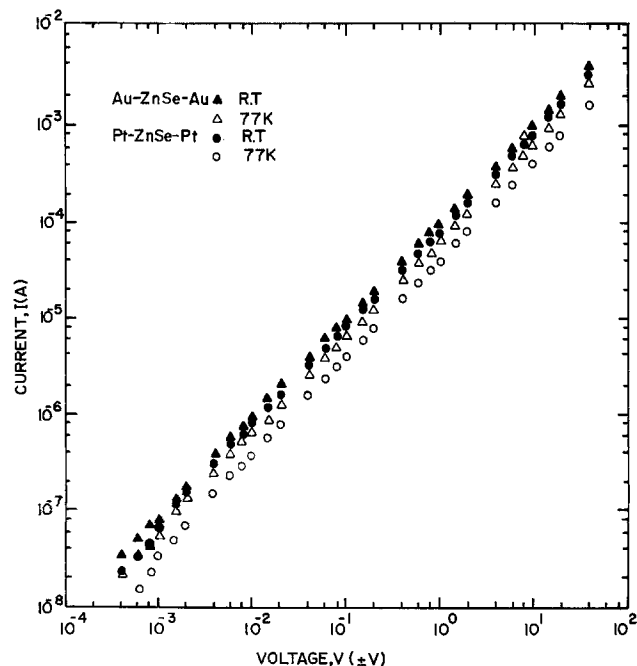


Fig. 1. I - V characteristics of Au and Pt contacts on Al-implanted, annealed ZnSe at 77° and 300°K.

is probably about the same. It was found that etching for about 1000 sec was necessary to reduce the conductivity to that of the original substrate. This suggests that the implanted layer, after annealing, was about 5 μm thick, giving an average doping concentration of about 10^{18} - 10^{19} cm^{-3} . Such a concentration is consistent with the observed nearly degenerate electrical characteristics.

Two Au (or Pt) contacts, of 0.1 cm diameter, were evaporated (or sputtered) 0.35 cm apart on the implanted, annealed surface. Current vs. voltage measurements were carried out at 77° and 300°K, over a voltage range of 4×10^{-4} -40V. The magnitude of the current was the same for both voltage polarities. The results are plotted in Fig. 1. Both Au and Pt contacts were found to be ohmic over five decades of voltage; however, the Pt did show some departure from ohmic behavior below 1 mV. The contact resistance, R_c , was determined from the relationship

$$R_c = \frac{1}{2} (R - R_{\square} L/W) \quad [1]$$

where $R \equiv V/I$, R_{\square} is the sheet resistivity [denoted by ρ' in Ref. (1)], L is the contact spacing, and W is the sample width. The results of this calculation are presented in Table I, but it must be emphasized that Eq. [1] is only approximate with our contact geometry. For comparative purposes we also list the contact re-

Table I. Contact properties of Al-implanted annealed ZnSe

Contact metal	Temperature (°K)	R_{\square} (kohm/ \square)	R (kohm)	R_c (kohm)	ρ_c (ohm-cm ²)
Au	300	8.76	10.40	2.13	16.72
	77	14.10	16.10	3.10	24.33
Pt	300	13.70	12.60	0.95	7.45
	77	28.50	25.40	1.60	12.56

sistivity (2), $\rho_c \equiv R_c A_c$, where A_c is the effective contact area, taken in this case to be just the actual contact area. It is seen that $\rho_c \approx 10$ -20 ohm-cm² for contacts produced in the manner described above.

The small temperature dependence of ρ_c suggests that a tunneling mechanism dominates the thermionic emission. For tunneling in a Schottky barrier at low temperatures and low bias voltages ($V \ll E_b/q$), ρ_c is dominated by (3, 4) $\exp(E_b/E_{\infty})$ where E_b is the effective barrier height, and $E_{\infty} \equiv (\hbar q/2) (N/\epsilon m^*)^{1/2}$. Here N is the doping density (assumed equal to the carrier concentration), ϵ is the specific permittivity, and m^* is the effective mass. If $N \approx 10^{18}$ - 10^{20} cm^{-3} , then E_b must be about 0.1-1 eV, a reasonable range, to give the right order of magnitude for ρ_c . However, this model would predict linear I - V characteristics only for $V \lesssim E_{\infty}/q$, and since $E_{\infty} = 20$ -200 meV for $N = 10^{18}$ - 10^{20} cm^{-3} we would not expect linear behavior above about 100 mV. The fact that such behavior is observed even at 10V suggests that the barrier becomes completely transparent in both forward and reverse bias conditions when a highly doped shallow layer having a surface carrier concentration of $\sim 10^{15} \text{ cm}^{-2}$ is formed.

Acknowledgments

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The Semiconductive Property of Gamma-Ferric Oxyhydroxide

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The recent investigations by Cohen *et al.* on the passive films deposited upon iron or platinum from neutral ferrous sulfate solution (1) or ferrous perchlorate solution (2) strongly suggest that the composition of these films corresponds to crystalline γ -FeOOH. It appears that the electrical properties of FeOOH-type oxides have not been studied extensively, although the

ultimate characteristics of such substances should have pregnant implications for the function of surface films.

In the preceding study on the electrical properties of ferric oxyhydroxides (3), the present authors found that α -, β -, and γ -FeOOH are semiconductors which show d-c conductivity in the order of $10^{-9} \text{ ohm}^{-1} \text{ cm}^{-1}$ and high-frequency (7 MHz) conductivity of 10^{-6} - $10^{-7} \text{ ohm}^{-1} \text{ cm}^{-1}$ and which probably have negative carriers. The appropriate value of conductivity ob-

Key words: passive film on iron, γ -FeOOH, electrical conductivity.